Journal of Animal Production, *30* (1), 28-35, 2018

Non-Linear Models for Growth, Development, and Posture of L-33 White Leghorn Hens, according to Economic Indicators

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ABSTRACT

The Zootechnical Factors established by the main indicators of bioeconomic behavior were determined for the productive-commercial cycle of L-33 White Leghorn hens in the province of Ciego de Ávila, Cuba. A number of 55 cycles were analyzed for validation of mathematical models between 2002 and 2014; other 18 cycles were studied between 2014 and 2016. Descriptive statistics, generalized mixed models (GLIMMIX), and five-function modelling were used. SAS 9.3 for Windows was also used. The productive cycles were similar to the standard set up for the breed and line in Cuba. Laying was 293 eggs/poultry, with a conversion of 1.40 feed kg/10 eggs, and a cost of $ 0.36 CUP an egg. The starting sheds and year had effects on live weight, tarsus length, uniformity, and daily weight gain up to 175 days. Sexual maturity, conversion, egg production, egg cost, and net income were influenced by farm, whereas each farm´s starting shed and the years, had negative effects on most biological indicators. Low, but significant effects of combined climate variables were observed in the bioeconomic indicators. The Gompertz´s model for growth, and Mc Nally´s for laying, were the best predicting tools for production. Along with GLIMMIX, they will contribute with suitable criteria for better decision making to increase egg production.

Key words: *mixed models, hens, farms, live weight, laying*

INTRODUCTION

The productive cycle of commercial hens begins with the arrival of one-day old chicks. The purpose at that age is to complete development of the digestive tract and the immune system, adequate beak cut, and proper lighting and hygiene (Carvalho *et al*., 2015).

One-day old chicks must have proper weight (most light breeds weigh 36 g). Low weight may be the cause of bird mortality during the first week of life, and it also affects development, as shown in flock disparities (Rodríguez and Valdivié, 2015).

The egg production period should also include environmental factors, management, and high laying potential of hens, which are not only achieved through greater posture persistence, balanced feeds, and optimum hygiene, but also through early development in the previous stage. It ensures production of 15-20 eggs per laying hen, with a fast start of production, proper beak persistence, and adequate posture plateau, indicators of high laying indexes, and sustained weight increases and egg quality, along with cost-effectiveness (Herrera, 2014).

Hence, the purpose of this paper was to determine the influence of fixed and random effects on economic indicators of the production cycle, and to check the predictive values of optimal mathematical models used for poultry growth and laying.

MATERIALS AND METHODS

This study was made on several farms of the Poultry Company of Ciego de Ávila, in the province of Ciego de Ávila, in central Cuba, on 21°.56 north latitude and 79°.10 west longitude. The topography is mostly flat, 27 m above sea level (Esquivel, 2013).

The study comprised a starting farm and six laying farms. Overall, 73 flocks were included from a 17-year period (55 flocks between 2002 and 2014; 18 flocks were used for model validation between 2014 and 2016.

Selection and sample description

Two populations were used: one for the study of zootechnical factors, and the other for validation of best fit mathematical models.

The period comprised in the study were, start (42 days), growth and development (43-112 days), adaptation (113-175 days), and laying (176 days on).

ISSN 2224-7920

The effects of age or production month were considered for modelling, and adjusted for the other effects of the model (relative humidity, wind velocity and temperature), in relation to evaluation of live weight (LW), tarsus length (TL), and laying intensity (LI). The experimental unit used was the shed, and evaluations were made at ages 1, 15, 30, 42, 64, 84, 112, 140, and 175 days. The monthly laying intensity occurred at 12 months, from day 175 to decrepitude.

Poultry management was made according to the technical instructions manual of IIA (2013). Proc NLIN was used for growth and laying.

The estimation of the parameters for the non-linear models required iterative methods. Model validation included the determination coefficient (R2), and the adjusted determination coefficient (R2A). For every monthly period, the daily mean, standard deviation (SD), standard error (SE±), variation coefficient (VC%) and the Durbin-Watson (DW) test with significance were calculated. The modified Gauss-Newton method available in pro NLIN SAS, 9.3 was used. The adjustment criteria recommended by Guerra, Cabrera and Fernández (2003), Macciotta *et al.* (2005, 2006) and Torres *et al.* (2012) were used for model selection.

Data analysis

Ins Ight, SAS (2010) was used to analyze normality through the Kolmogorov-Smirnov test. The best fit analysis was made for data transformation through Proc Severity.

A generalized mixed linear model (Pro Glimmix), suggested by Wolfinger and O´Connell (1993) was used for data analysis, considering the random effect choice. The Tukey-Kramer (Kramer, 1956) test was used for comparison of significant means below 5%.

Measure adjustments for all the analyses were made using Logn distribution with Link Identity, according to Proc Severity. Transformation was made through Euler-based power function (e).

Mathematical functions used

The non-linear models below were selected to study the growth and laying curves after an initial study of more than 14 models for the two stages.

Growth stage

Functions	Year	Equation
Gompertz	1925	$Y=a\ e^{(-b\ e(-c\ x)}$

Where:

Y: dependent variable in g/poultry or mm for LW and TL, respectively

(a, b, c and e): model parameters

X: independent variable measured in time (days).

Laying stage

Functions	Year	Equation
Mc Nally	1971	$Y= -a\ Xb\ e^{(-cX + dX ** (0,5))}$

Where:

Y: dependent variable, laying intensity (%)

(a, b, c, d and e): model parameters

X: independent variable (months).

For selection of the best model, the following adjustment criteria were considered, according to Guerra, Cabrera and Fernández (2003), Macciotta, Vicario and Cappio-Borlino (2005), Macciotta *et al.* (2006) and Torres *et al.* (2012):

1) R^2 and R^2 adjusted to the model´s freedom range.
2) The mean square value of prediction error (MSE).
3) The model´s significance test.
4) Significance test of parameters.
5) The number of iterations that determines the greater or lower convergence difficulty.
6) Graphic distribution of residues.
7) Atypical percent curves consider R2 below 0.50 and 0.90% at Pro NLIN, SAS (Steri, 2013) output.

Defined integral used at growth, development, and laying.

The definite integral was used to determine the area under the growth curve, as an example of model application in silico to help make decisions. The integrals below were used for growth and laying.

$$\int_1^{175} \mathbf{1681.21 * 2.72\ (-3.37\ 2.72\ (-0.20\ age)}$$

$$\int_3^{14} \mathbf{711.8month}^{(\mathbf{2.286*2.72(-0.222\ month)+(-3.096month))}}$$

The online procedure described by Scherfgen (2016) was used.

The primary data related to economic variables collected from the accounting records of the farms studied were included and considered within the official prices set in the sector (CANCA, 2016). The data was used to calculate prices in CUP (Cuban Peso) of the items below, Cost of egg (COH) = cost of replacement and cost of the laying hens/number of eggs produced per lodged hen.

Net income per produced Peso, not considering income from decrepitude (INPPRO) = total income without decrepitude minus the total expenses/total expenses.

Net income per produced Peso, considering income from decrepitude (INPPRO) = total income without decrepitude minus the total expenses/total expenses.

RESULTS AND DISCUSSION

Table 1 shows that for the start of growth and development of chicks, the Gompertz (1925) model had adequate stage adjustments, considering the very same criteria used in the experimental stage. In both cases, the model evaluated showed that the asymptotic weight (a) was higher than the maturity rate (c). However, the integration coefficient (b) was lower than (a), and higher than (c), with model and parameter significance.

In terms of mean daily gain (MDG), modelling of live weight based on age for validation of replacement chicks' growth ranged between 8.6 and 12.3 g/bird/day, close to the standards set for L33 White Leghorn hens (IIA, 1998, 2003, 2013).

Mc Nally´s model (1971) was well adjusted for laying. Also significant were the model and its parameters, similar to previous results.

Similar results were achieved by Savagnago *et al*. (2012), who were able to predict the production of White Leghorn hen eggs, using six models with proper adjustment criteria. The best predictive behaviors were observed with the logistic Yang, segmented polynomial, and Grossman (5-54 weeks of production), who achieved laying peaks above 92%, and high persistence on the laying plateau (282 eggs per lodged bird), and mass conversion of 1.69 kg of feed per every egg kg.

The definite integral of the curve was also considered an alternative to calculate the laying yields, where 70% was the average laying intensity under the curve. Egg production throughout the year was 255.5 eggs/bird, which is typically found in this province. Fraga *et al.* (2003), in a preliminary study of lactation in crossbred buffalo cows, used the definite integral to predict milk production.

Table 2 shows a comparison of the adjustment criteria between both stages in the study, according to Guerra, Cabrera and Fernández (2003), and Torres *et al*. (2012). The adjustment criteria of the growth model of Gompertz worked well with R2 adjusted to 99.27%, very similar to the value achieved in the previous study (99.13%), accompanied with an absolute mean error of 20.69, smaller than the one achieved in the experimental study that lasted 14 years (26.17). The standard deviation for the estimation error was 50.09, very similar to the previous 51.16.

The adjustment indicators for model validation were appropriate, as 0.95 was observed for standard deviation of estimation error, very similar to the 0.97 found in the previous study. A value of 1.29 was observed for the absolute error mean in this study. It was similar to the 1.32 observed in the experimental stage and the Durbin Watson statistics, close to 2. It proved the inexistence of self-correlation of validation or experimental model errors.

It meant that the expression described the monthly variation of the laying intensity of L33 White Leghorn hens in the province of Ciego de Ávila, between 2014 and 2016, similar to Mitat and Fernández (2012) who used the same method to predict production and other indicators, in a lactation curve study in buffalo cows. Although those studies did not include birds, they did show a high predictive value for animal production.

The Gompertz function (Fig. 1) did not over estimate live weight in any of the curve points, which might be explained by the pealing after 65 days of raising, as well as the number of chicks submitted to the process (Sacranie *et al.*, 2015). It caused a reduction in voluntary consumption of up to 17 days, thus producing a decline in growth increase rates.

Botelho, Serafim and Butolo (1998) said that the behavior observed was proportional to the weight-age ratio in normal production conditions. These results also coincided with other results from Galeano-Vasco and Cerón-Muñoz (2013), who stated that commercial lines were able to reach live weights above 1 550 g.

In the laying study (Fig. 2), the best model (Mc Nally, 1971) did not overestimate the maximum values in relation to the peak of egg production found at the beginning of the second month of laying, with 91.4%. Forainne (2016) in a study of Hy Line hens, found that the production peak was between the end of the first month and the beginning of the second, after the incorporation of hens to production, very similar to the values achieved in this study. That author reported a laying intensity that averaged 90.7-91.2% within the month, also similar to this study.

Mc Nally´s model was also considered to provide a better characterization of egg production in Ciego de Ávila; other models could also be used in further studies that allow the analysis of factors that affect the laying curve, like reaching sexual maturity, phase-based and balanced diets, and climate.

Fialho, Ledur and Ávila (2001) used the segmented polynomial model to predict the age at which laying began, and when the laying start and peak were produced. This expression described egg production best in L33 White Leghorn hens, in Ciego de Ávila, compared to all the other models. However, in an atypicality study, Alí-Schaeffer's model showed 0% values under R2 =0.90; whereas Mc Nally had 90.7 % below R2 = 90 %. In an analysis of other adjustment criteria, Mc Nally´s was the best, as shown in table 2.

Economic results

Table 3 shows the variance analysis for these indicators, with the significant effects observed in the laying farm ($P < 0.05$), and the starting years for variables COPH, INPP and INPPD. The maintenance cost of a laying hen was more than twice the cost of its replacement; egg cost was $ 0.36 CUP, whereas the net income per Cuban Peso was $0.42, regardless of the sales of decrepit hens. The $0.51 CUP value was the average considered during the 14-year period studied, which made it economically appealing.

The ED, VC, and SE values were low, which meant that the indicators had very little variation during data collection. Ferrufino and Rosales (2005) reported inferior values using ISA-Brown commercial laying hens, in Santa Cruz, Bolivia. They achieved egg costs at $0.43 per produced Peso; however, the cost of hen maintenance improved from $68.91 Pesos, to the $70.84 CUP in this study.

Table 4 shows that the laying farms No. 5 and 6 had the best behavior in the three economic indicators evaluated, a reflection of the farm effect associated to the improvement of productive indicators. These results were closely related to a more efficient work done by the farmers, technicians, and management.

Inferior results were reported by Pérez (2011), who improved the laying intensity in 4.5%, and lowered egg costs to $0.41 CUP, after evaluating the effect of hydrotherapy on the productive behavior of laying hens at the Poultry Company in the province of Tunas. Besides, Castellanos (2011) achieved better egg production costs in L33 White Leghorn hens in cages, the best behavior ($0.39 CUP), including the results of this paper.

Moreover, Farm No. 6 (Primero de Enero) was an example of the previous results, regarded for several straight years as a national reference. These indicators must be considered as reference, though they can be improved (CANCA 2017; UECAN 2017).

Table 5 shows that egg costs and net income per produced Peso, regardless of decrepitude, had significant differences ($P < 0.05$) during the years evaluated.

Income in CUP was elevated thanks to the egg sales resulting from replacements that met the live weight and uniformity standards at 18 weeks of age. It justified the need for laying hen replacements with adequate live weights, uniformity, and timely sexual maturity. Nevertheless, this study showed that replacements with lower values caused huge economic losses in the long run.

The best income years were 2002, 2003, and 2008 ($P < 0.05$), when decrepitude was not considered. The cause of variations between years may be found in the ups and down in the prices of feeds, diseases, and changes associated to the THV categories (combined temperature values, relative humidity, and wind velocity), and climatic changes that may have caused stress in the birds.

CONCLUSIONS

The mean bioeconomic indicators of 18 productive cycles for the validation of commercial L33 White Leghorn hens in Ciego de Ávila were generally characterized by their approximation to the standard values for the breed and line in Cuba (1 588 g at 175 days; 1.40 kg/10 egg conversion; and 294 eggs/hen on average). The cost of egg production was $0.36 CUP, with a net income of $0.42 CUP, regardless of decrepitude.

The Gompertz's functions (1925) for growth, and Mc Nally´s (1971), for laying in L33 White Leghorn chicks and hens, respectively, reached the best kindness adjustment criteria, and they were validated as predictors for the productive cycle, showing their potential for decision making.

Recommendations

A new computer application based on the predictive value of the models used in this study would be a useful tool for the Poultry Company to make predictions and make proper decisions to increase egg production.

Further studies should assess the behavior of the productive cycle of laying hens, considering the effect of environmental conditions *in situ*, as well as the subjective factors that set differences of productive indicators among farms and houses.

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Received: 7-12-2017
Accepted: 7-20-2017

Table 1 Validation of Laying Curves of L33 White Leghorn Hens in 2014-2016, in the Province of Ciego de Ávila, Cuba

Models	Parameters			
	± SE	b ± SE	c ± SE	d ± SE
Gompertz (1925)	1 681.21 ± 11.747	3.37 ± 0.039	0.20 ± 0.003	-
Mc Nally (1971)	711.80 ± 108.710	2.29 ± 0.009	- 0.22 ± 0.020	- 3.09 ± 0.183
Significance of parameters				
Gompertz (1925)	***	***	***	
Mc Nally (1971)	***	***	***	***
Resulting equations				
Gompertz (1925)	$Y_{e=}$1 681.21 * 2.72 (-3.37 *2.72 (-0.20 *age)			
Mc Nally (1971)	Y_m = 711.80 * month $(^{2.29* 2.72((-0.22* month)+(-3.09* month(0.5))})$			

Parameter: (a) asymptotic value of growth and laying; (b) adjustment parameter; (c) growth rate and posture; (d) adjustment parameter for laying
*** (P < 0.001)

Table 2. Comparison of models used in the experimental phase (1) and validation (2) of results in the growth and laying periods

Models	Parameters			
	Gompertz 1	Gompertz 2	Mc Nally 1	Mc Nally 2
Model significance	***	***	***	***
Determination coefficient R2	99.34	99.53	99.60	99.76
Determination coefficient R2A	99.13	99.27	99.42	99.54
D. Standard error estimation	51.16	50.09	0.97	0.95
Absolute mean error	26.17	20.69	1.32	1.29
Durbin-Watson test	2.10	2.04	2.13	2.09
Significance	**	**	**	**

R^2A adjusted determination coefficient, D deviation
*** (P < 0.001)
*** (P < 0.001)

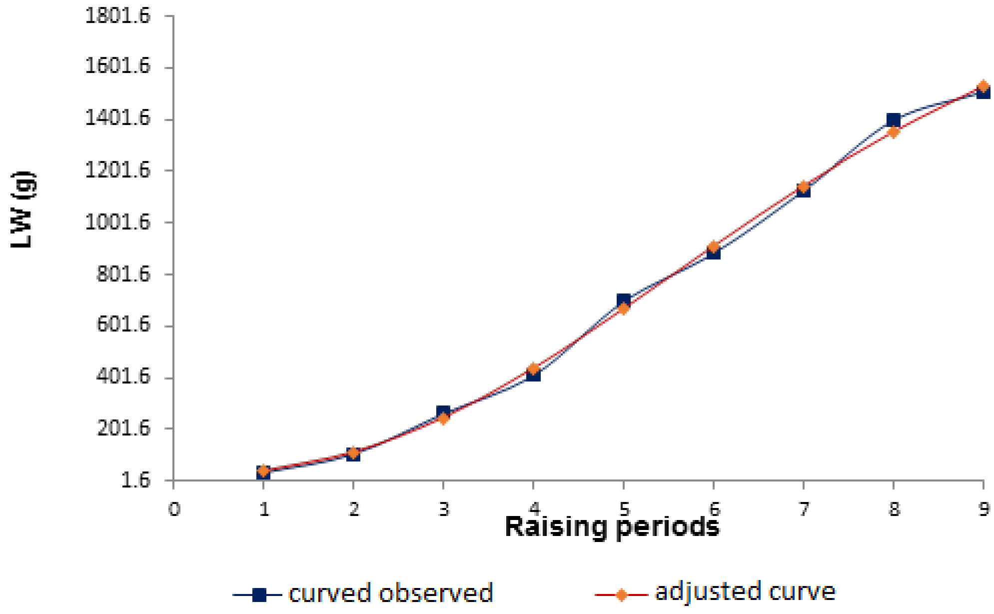

Fig. 1. Curves observed and estimated in the model of Gompertz (1925) validated for the growth period

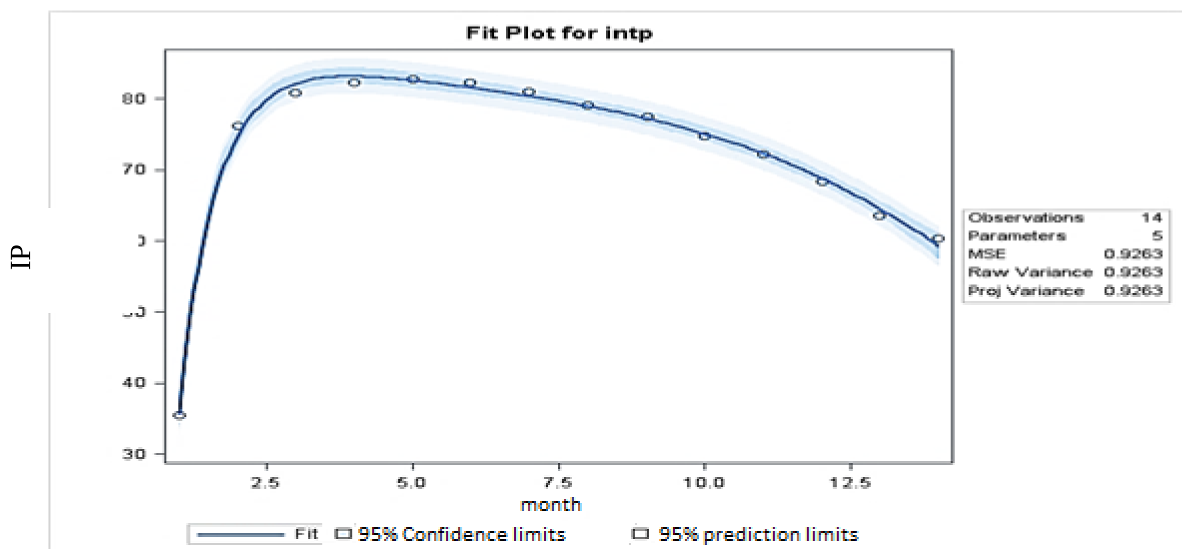

Fig. 2. Curves observed and estimated in the model of Mc Nally (1971) validated for the egg production period SAS output

Table 3. Influence of fixed effects on some economic indicators evaluated in L33 White Leghorn hens

Effects	GL (Num/Den)	P value				
		COCO	COPON	COPH	INPPRO	INPPROD
Farms	5/213	0.2907	0.2664	0.0164	0.0140	0.0131
NI/NC(G)	30/213	0.6995	0.8288	0.0595	0.0685	0.3848
Year	13/213	0.5788	0.4818	0.0166	0.0156	0.0202
CA	3/213	0.0447	0.0545	0.3722	0.3987	0.7531

Num/Den: Numerator/Denominator; CA: flocks per year; COPON: cost of a single laying hen; COCO: cost of chicks and laying hen at start of production; COPH: egg cost; INPPRO: income per produced Peso; INPPROD: net income per produced Peso, plus decrepitude.

Table 4. Effect of production farms on some economic indicators (CUP) evaluated in L33 White Leghorn hens

Farms	COPH		INPP		INPPD	
	Mean	SE±	Mean	SE±	Mean	SE±
1. S. Tomás	0.360^{b}	0.003	0.420^{b}	0.005	0.516^{b}	0.006
2. A. Voisin	0.370^{a}	0.004	0.408 c	0.004	0.497^{d}	0.006
3. XXX Aniv.	0.362^{b}	0.003	0.418^{b}	0.004	0.504 c	0.005
4. M. Morales	0.363^{b}	0.003	0.416^{b}	0.004	0.508 c	0.006
5. Florencia	0.356 c	0.003	0.424^{a}	0.004	0.515^{b}	0.006
6. P. Enero	0.355 c	0.003	0.426^{a}	0.005	0.523^{a}	0.006

[a,b,c,d] Means with unequal superindexes on the column differ significantly
* ($P < 0.05$), according toTukey-Kramer (Kramer, 1956)
COPH: egg cost; INPPRO: net income per produced Peso; INPPROD: net income per produced Peso, plus decrepitude.

Table 5. Egg cost and net income per produced Peso (CUP) in L33 White Leghorn hens

Years	COPH		INPPRO		INPPROD	
	Mean	SE±	Mean	SE±	Mean	SE±
2002	0.35^{d}	0.005	0.43^{ab}	0.006	0.53^{a}	0.008
2003	0.35^{cd}	0.004	0.43^{a}	0.005	0.52^{b}	0.008
2004	0.37^{b}	0.004	0.41^{cd}	0.005	0.50^{d}	0.008
2005	0.36^{c}	0.004	0.42^{c}	0.005	0.51^{b}	0.007
2006	0.37^{a}	0.005	0.41^{e}	0.006	0.49^{e}	0.009
2007	0.36^{d}	0.004	0.42^{b}	0.006	0.524^{b}	0.008
2008	0.36^{bc}	0.004	0.43^{a}	0.005	0.514^{c}	0.007
2009	0.36^{b}	0.004	0.42^{c}	0.006	0.52^{b}	0.008
2010	0.37^{b}	0.004	0.41^{cd}	0.005	0.49^{e}	0.007
2011	0.36^{c}	0.004	0.41^{cd}	0.005	0.50^{d}	0.007
2012	0.35^{d}	0.005	0.42^{c}	0.005	0.50^{d}	0.007
2013	0.37^{a}	0.010	0.42^{c}	0.005	0.5^{c}	0.009
2014	0.35^{a}	0.009	0.40^{e}	0.012	0.49^{e}	0.014

a,b,c,d : Means with unequal superindexes on the column differ significantly, according to Tukey Kramer (1956)
COPH: egg cost; INPPRO: net income per produced Peso; INPPROD: net income per produced Peso, plus decrepitude. ($P < 0.005$)